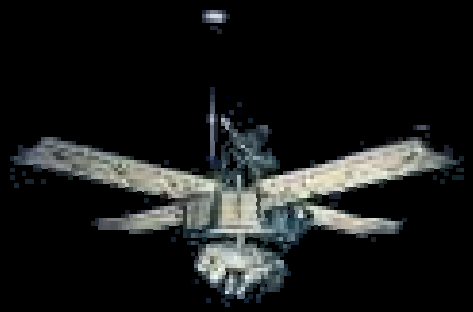
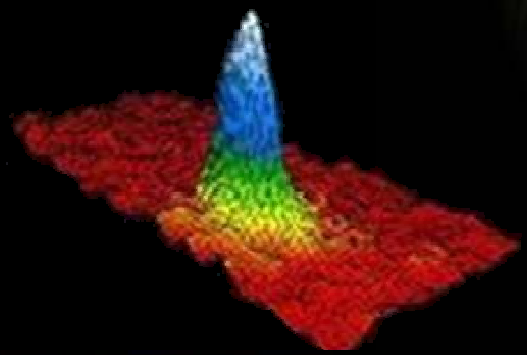
QUANTUS

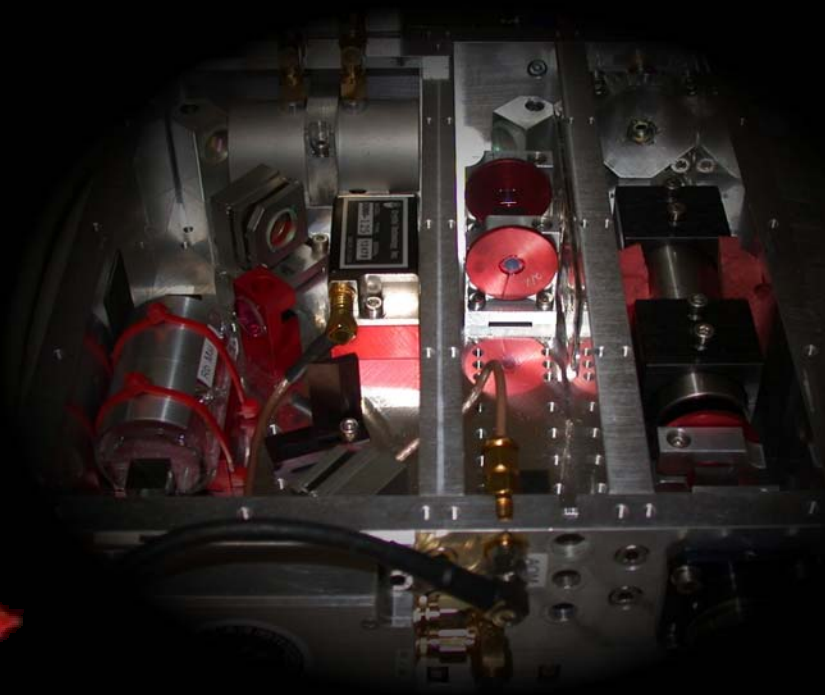
Quantengase Unter Schwerelosigkeit
(Quantum Gases under Microgravity)

Achim Peters

for the **QUANTUS** team

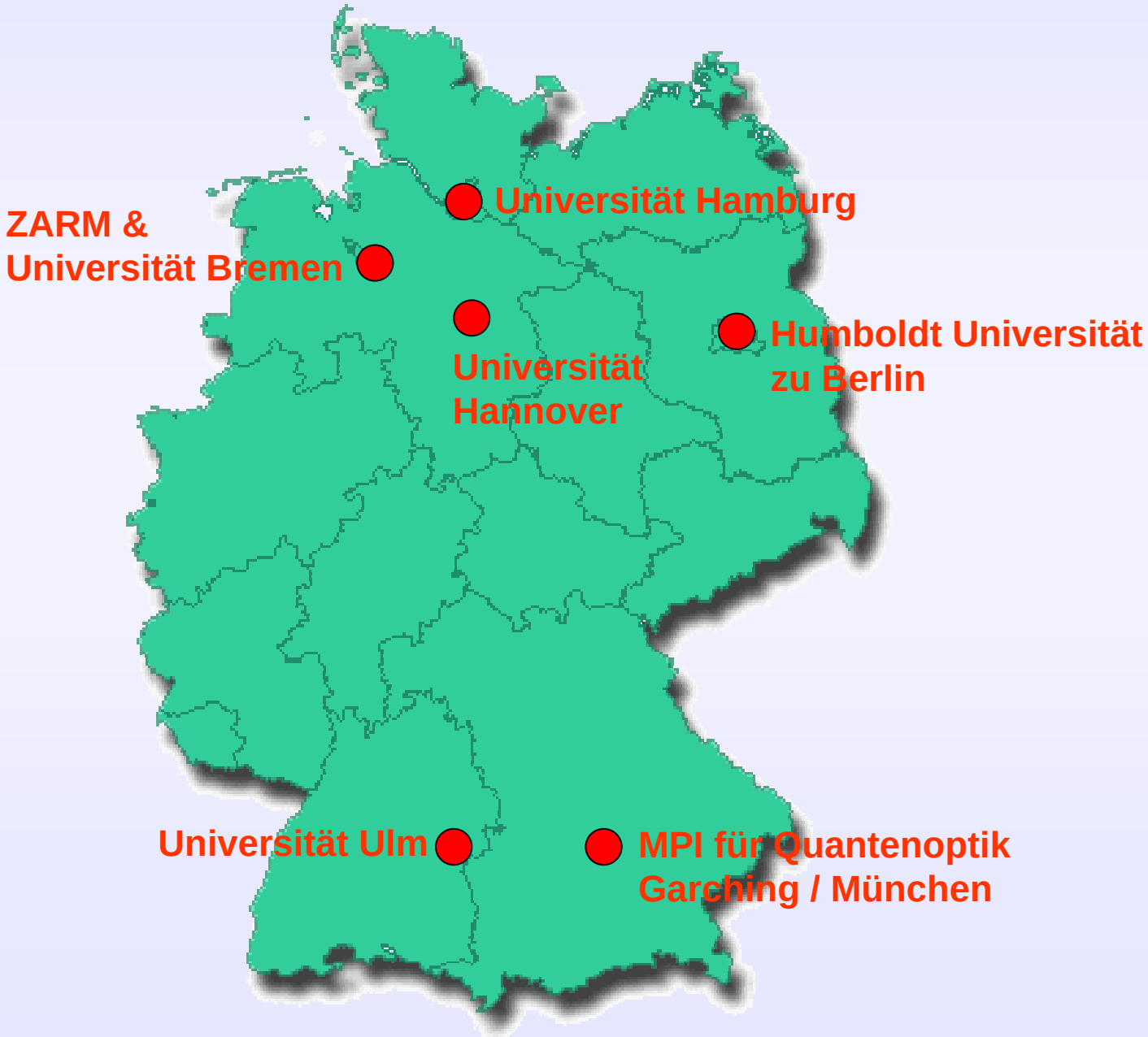






Workshop on Advances in Precision Tests and Experimental Gravitation
Galileo Galilei Institute for Theoretical Physics, Arcetri, Firenze, 28th September 2006

The QUANTUS Team



Funding:

DLR

DLR 50 WM 0346

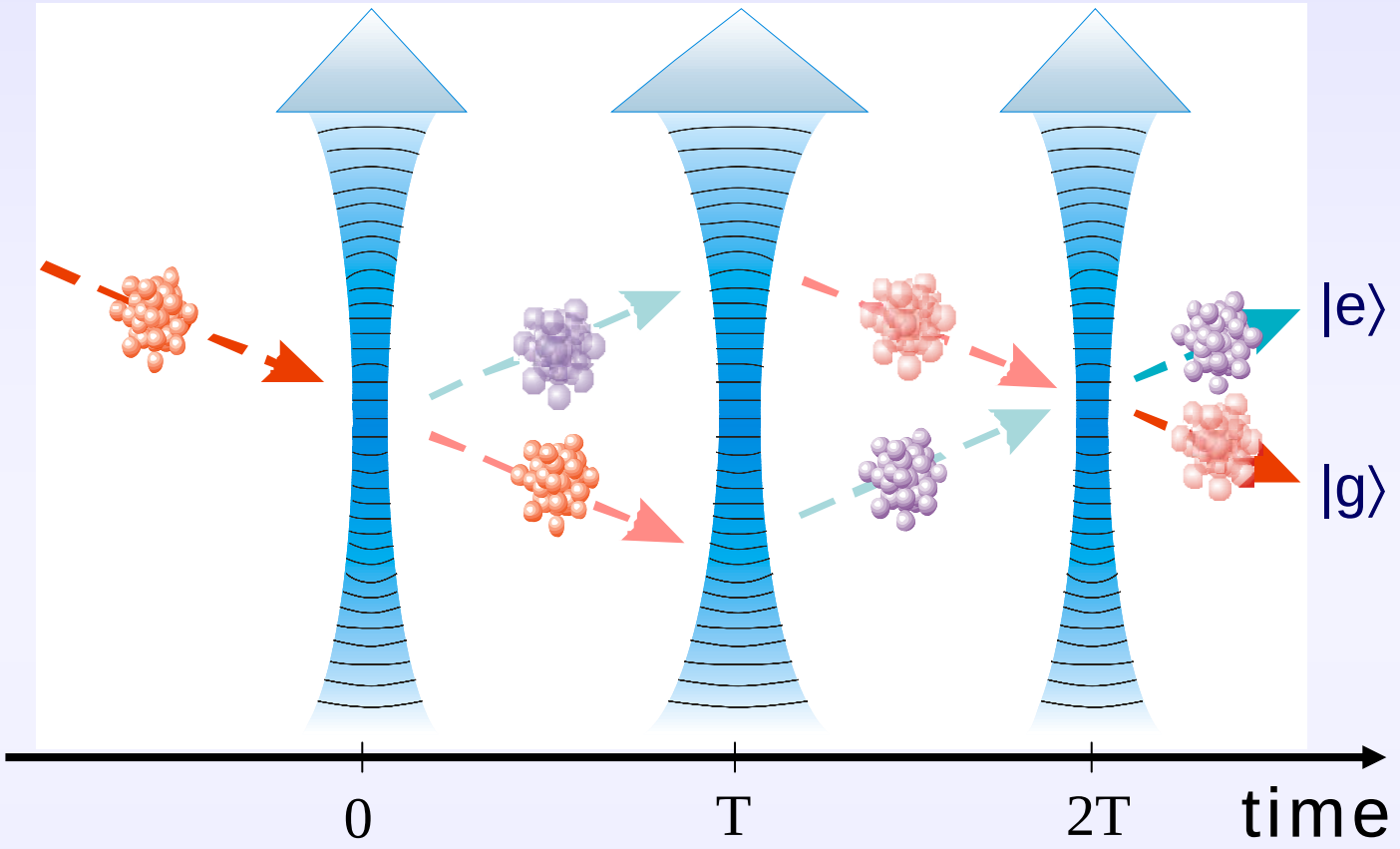
BEC in Free Fall:
Shifting the Frontiers in Physics

Longest time of flight for quantum objects

Lowest temperatures / energies

Largest quantum objects

Long Evolution Time ➔ High Sensitivity



Signal at the output ports

$$S \propto f(\mathrm{T}) \propto \begin{cases} \mathrm{T} \text{ for frequency, recoil, rotations} \\ \mathrm{T}^2 \text{ for gravity, gravity gradients} \end{cases}$$

See e.g. : Ch. J. Bordé, Gen. Rel. Grav. **36**, (2004), 475

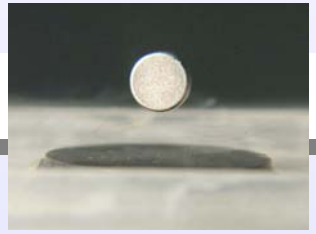
Lowest Energy Scales

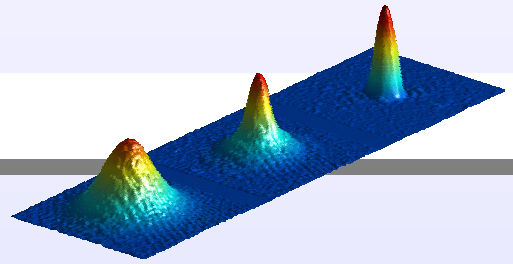
10^{-20} 10^{-23} 10^{-26} 10^{-29} 10^{-32} 10^{-35} 10^{-38} J

10^{-13} 10^{-16} 10^{-19} 10^{-22} 10^{-25} 10^{-28} GeV

10^{3} 10^{0} 10^{-3} 10^{-6} 10^{-9} 10^{-12} 10^{-15} K

current record:
450 pK
W. Ketterle et al.





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"classical" phase transitions

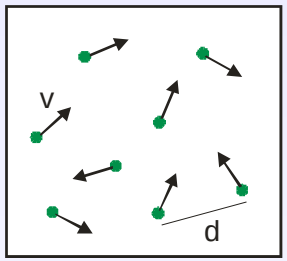
macroscopic quantum phenomena

"quantum" phase transitions

?

New Length Scales

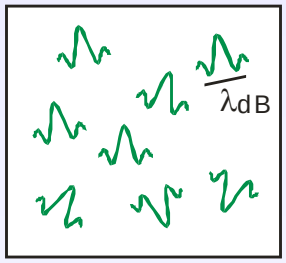
individual particles



$\lambda_{dB} < r_{cl}$

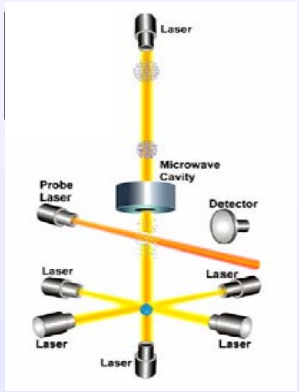
classical gas

individual wave packets

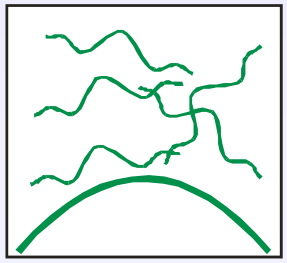


$\lambda_{dB} < d$

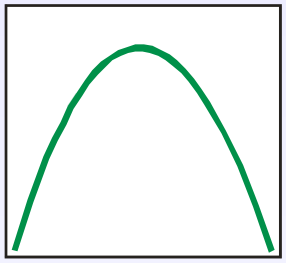
precision measurements



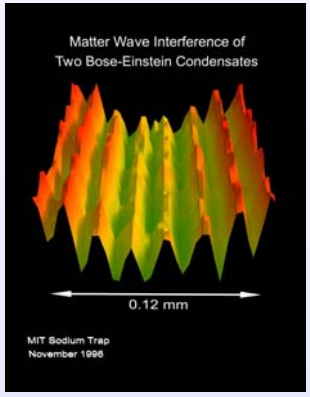
macroscopic matter wave



$\lambda_{dB} > d$

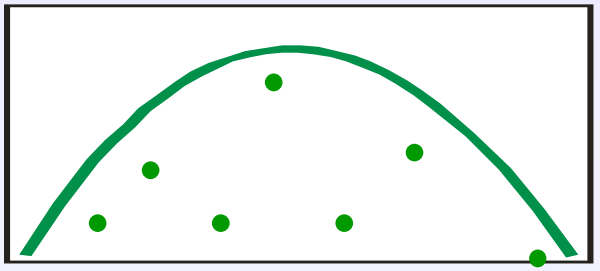


sub mm scale



macroscopic coherence

QUANTUS



mm to cm scale

?

- coherence limits ?
- granularity
- space time fluct. ?
- ....

The ZARM Drop Tower

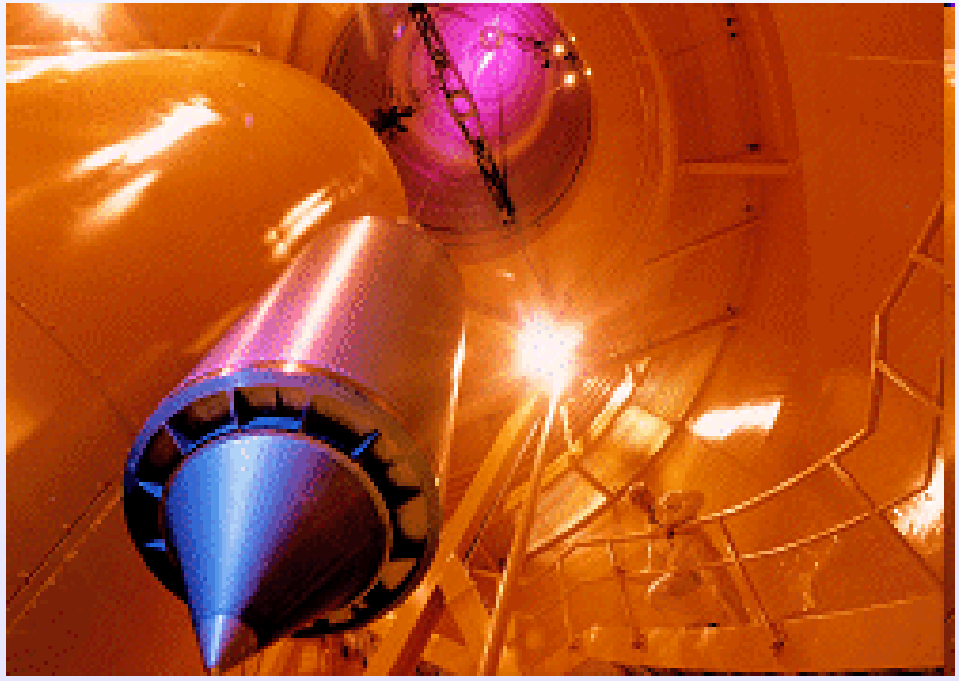
Free Fall: up to 4.5 sec

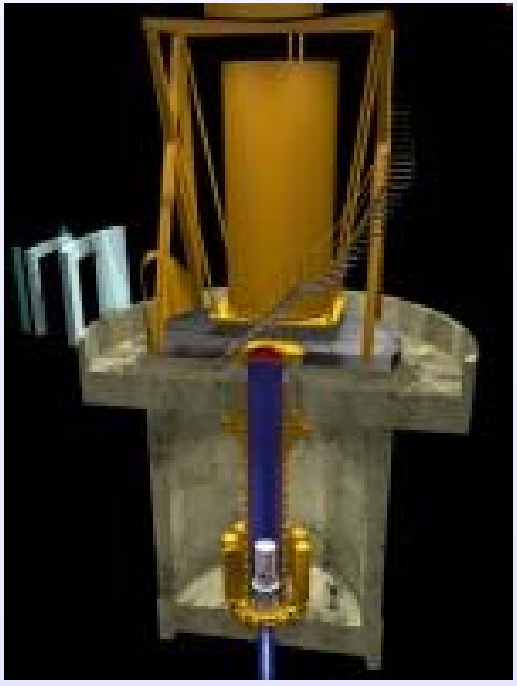
Duration > 1 BEC-Experiment

3 flights per day

Test of a robust BEC Facility
Dimensions < 0.6 ∅ x 1.5 m

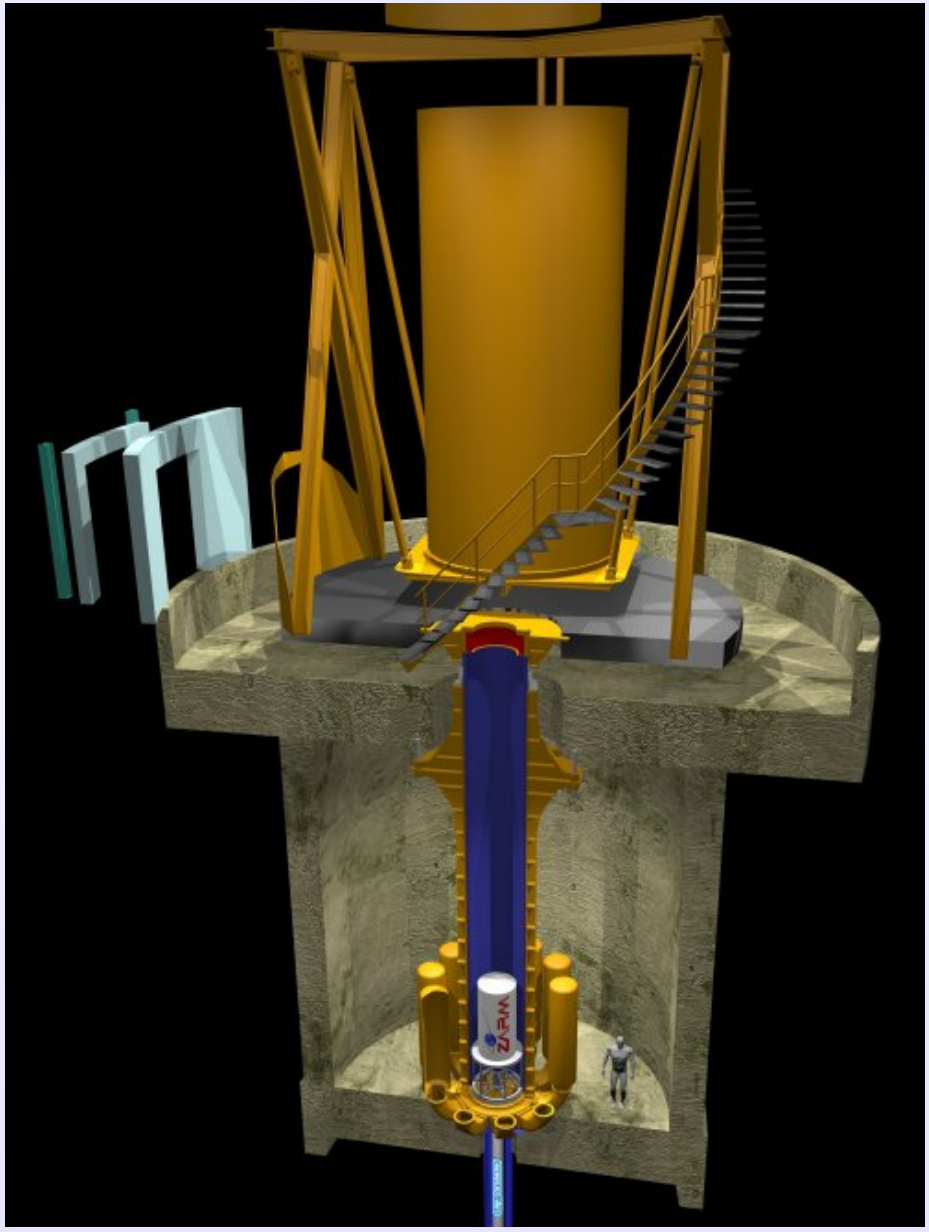
Height 110 m





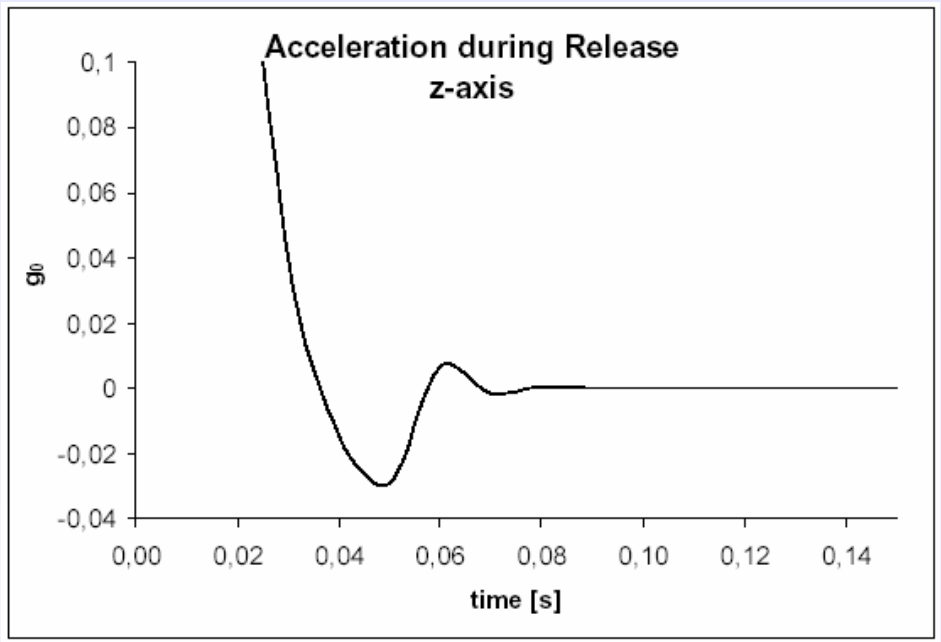
The ZARM Katapult

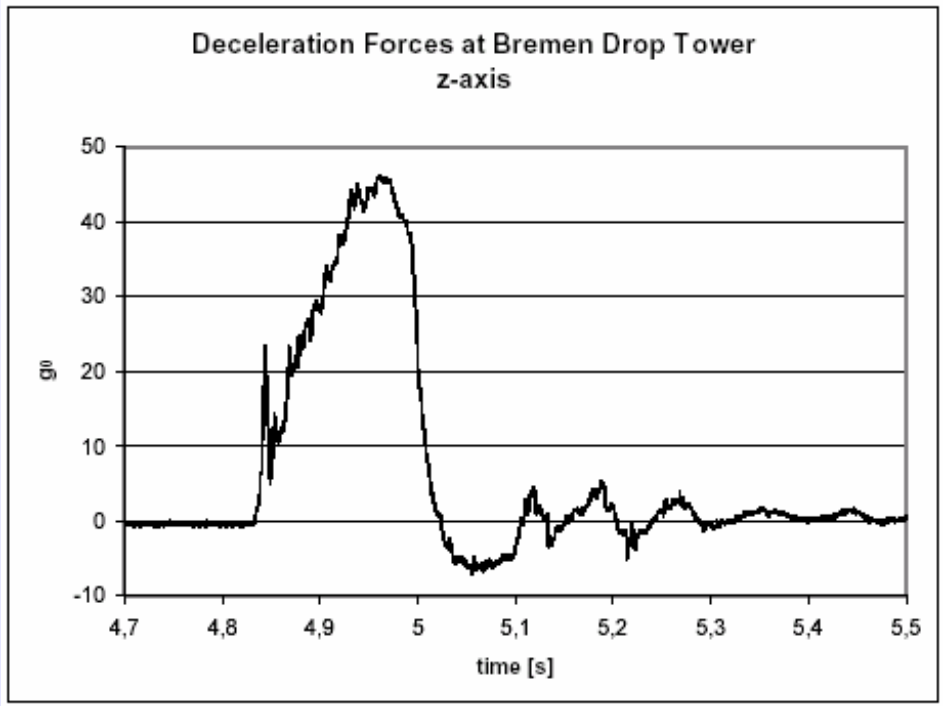
Doubling the Free Fall Time to 9 seconds ...



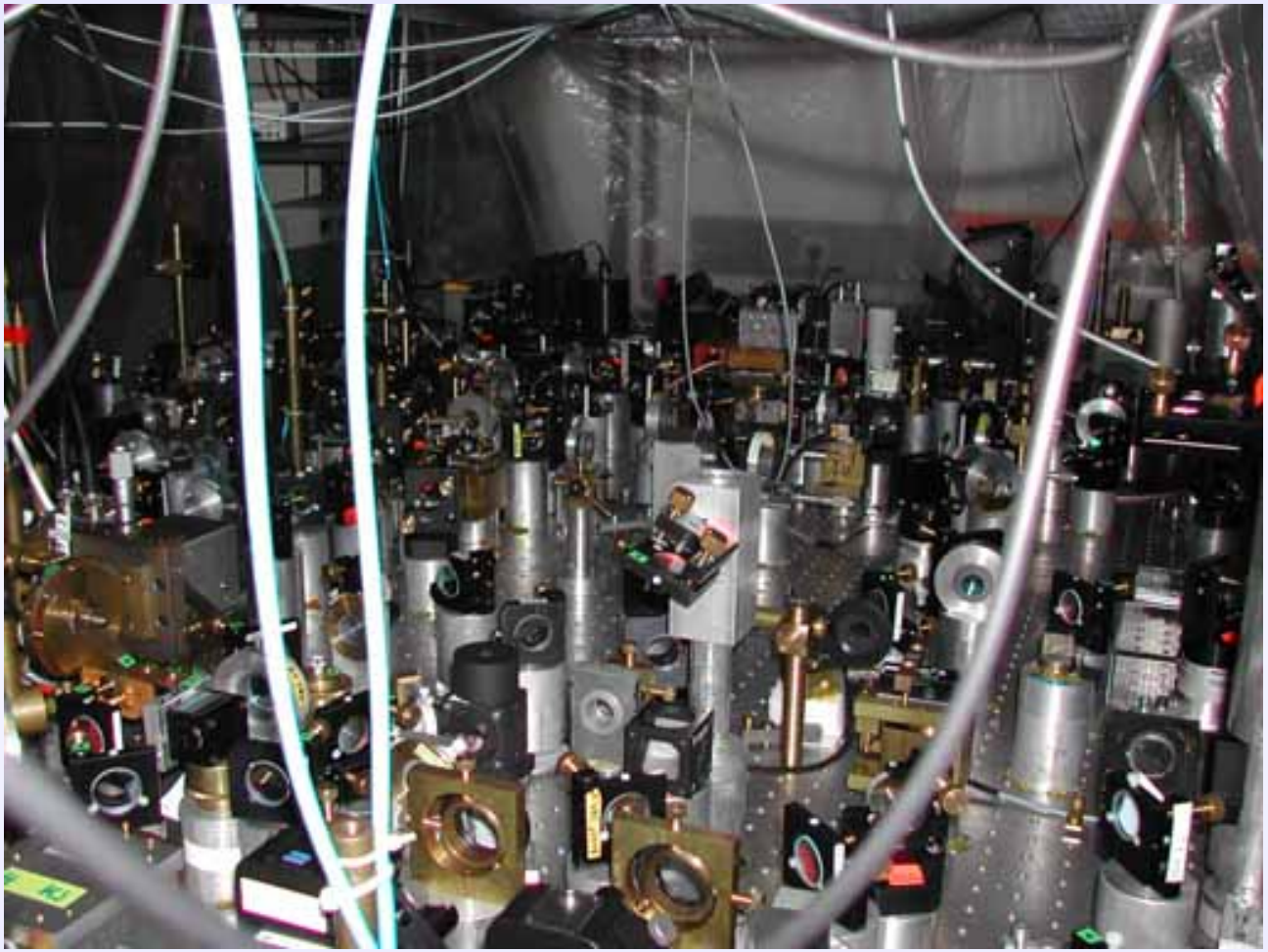
Experimental Environment

110 m ~ 4.74 s at µg acceleration





The Challenge ...



A typical BEC laboratory experiment

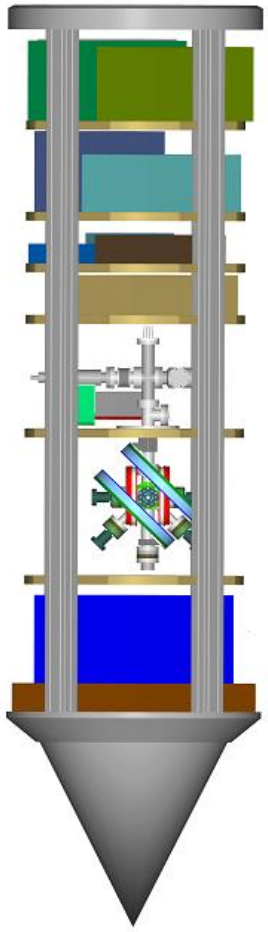
Drop capsule
boundary conditions

Laser

Electronics

Vacuum

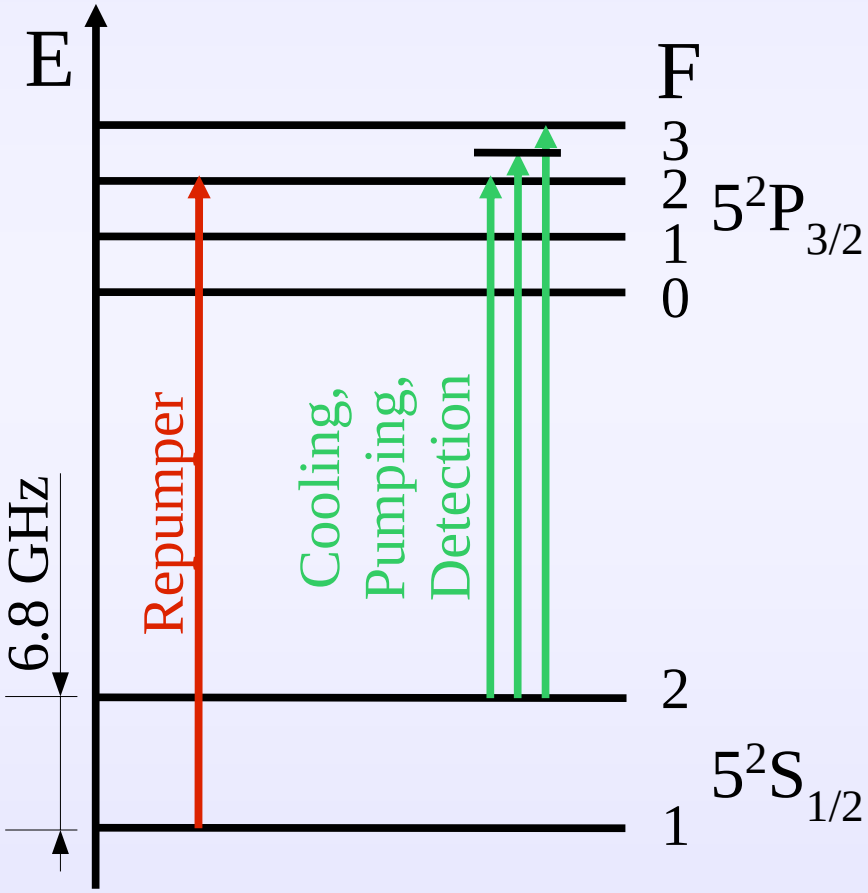
Computer



h = 1.73 m
d = 0.6 m
av. Power < 280 W
Weight < 274 kg

Laser System

Two frequency ranges required for ^{87}Rb BEC



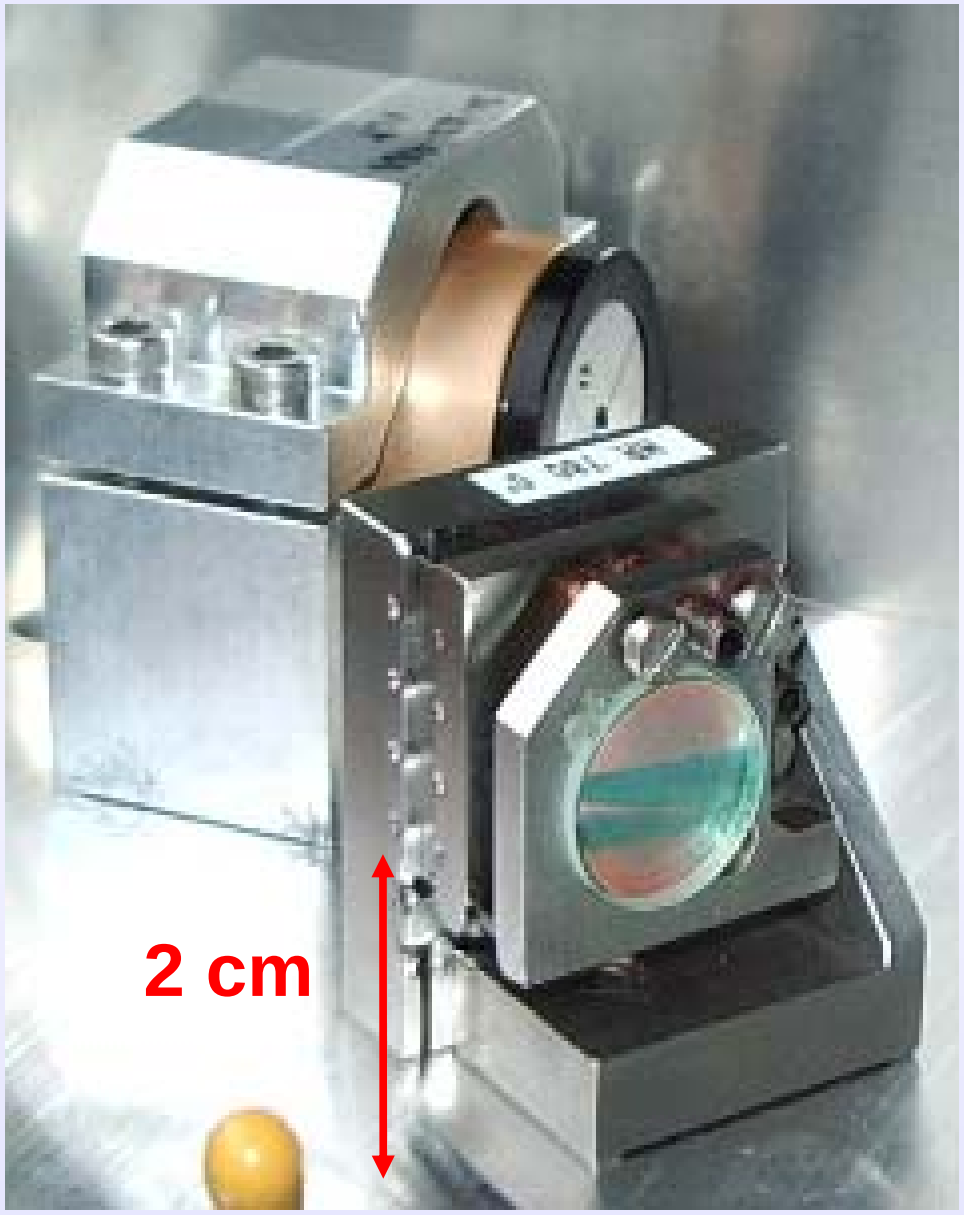
4 modules

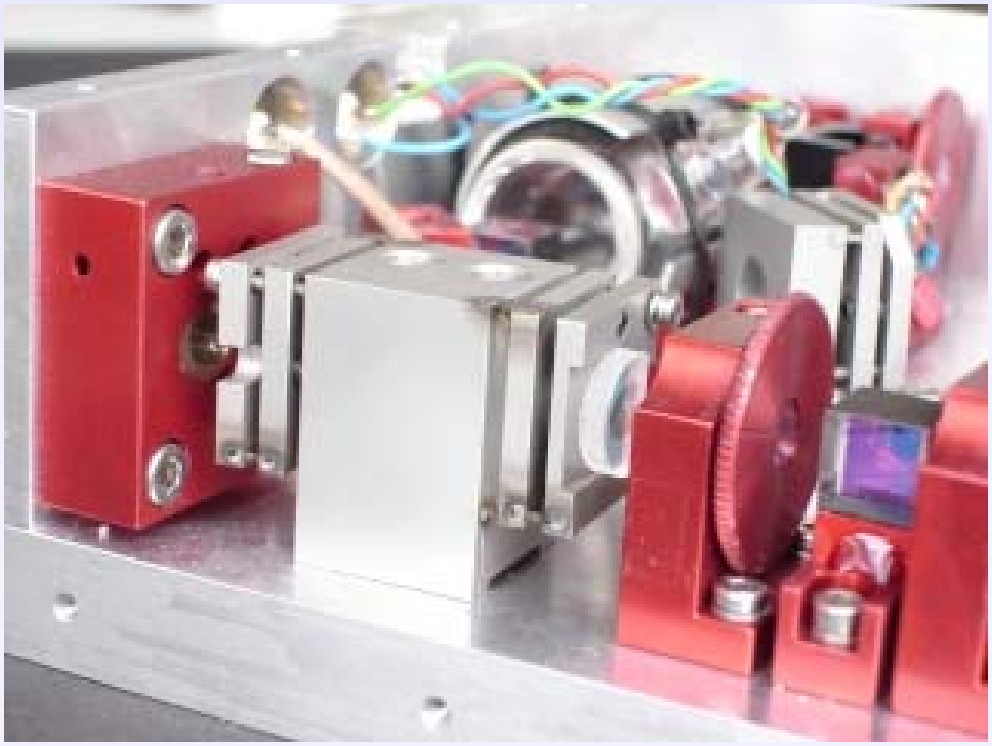
2 spectroscopy stabilized master laser

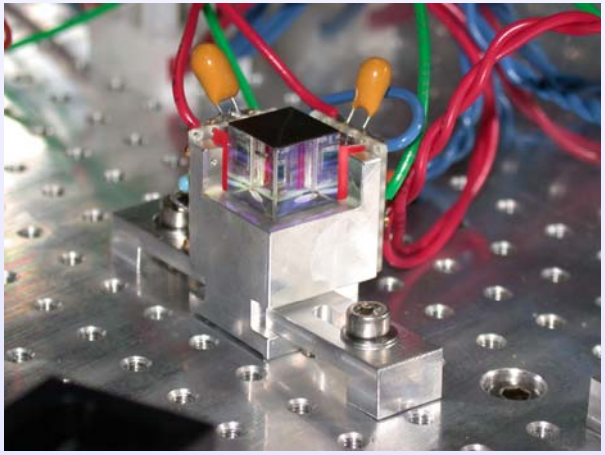
Beat stabilized MOPA amplifier module

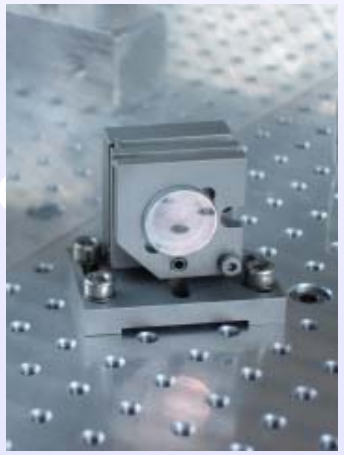
Distribution Module (AOM)

Mechanically Stable Optical Components

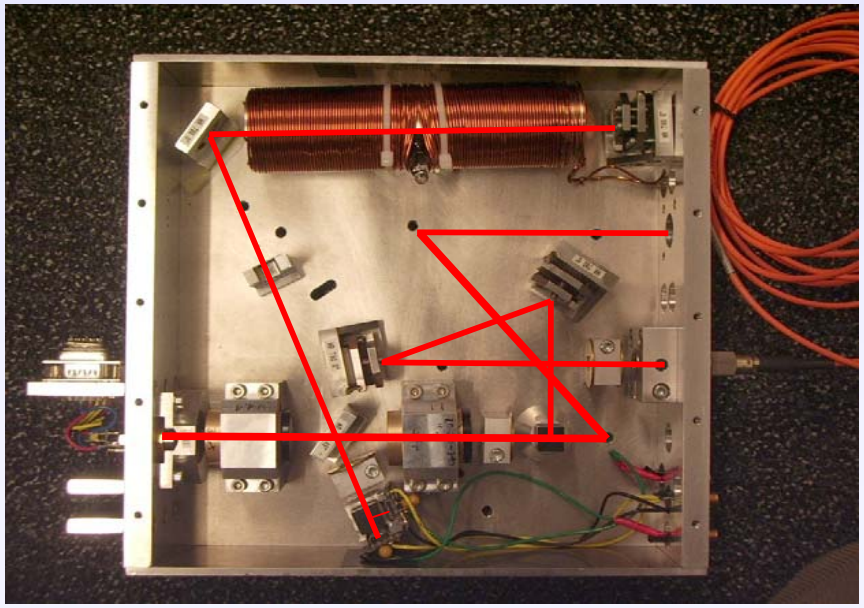








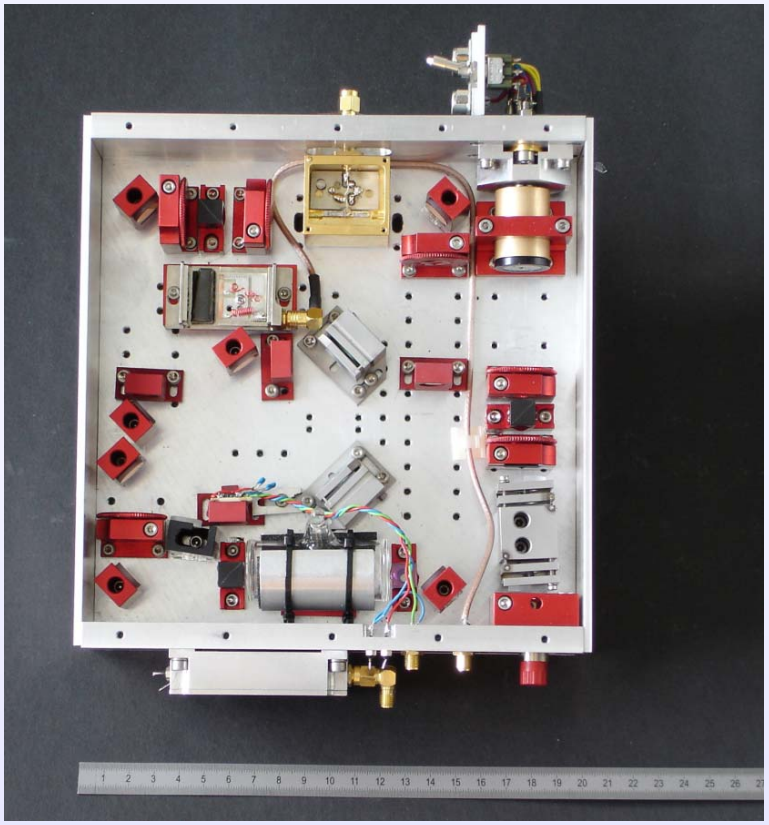
Laser Modules

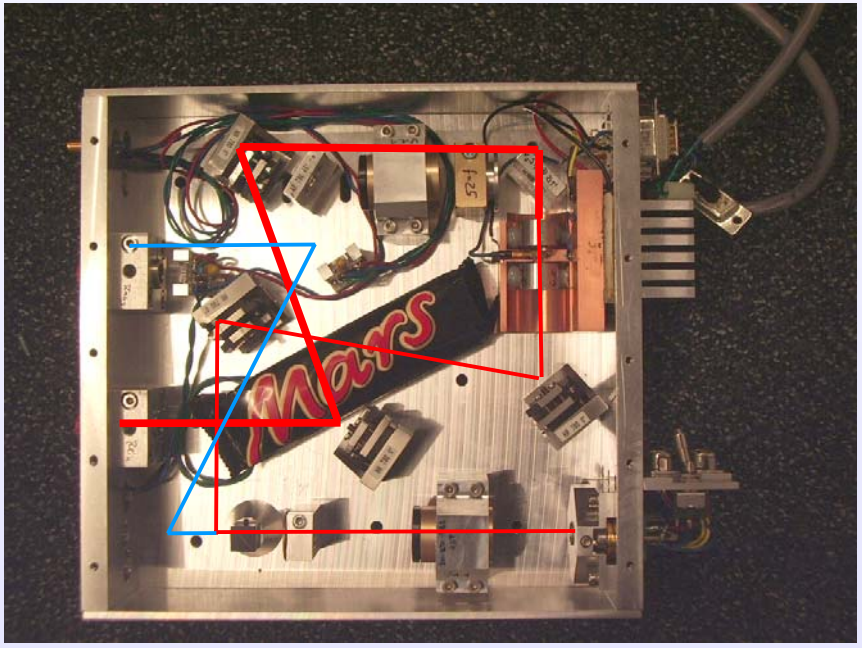


← DFDL master module

FM master module

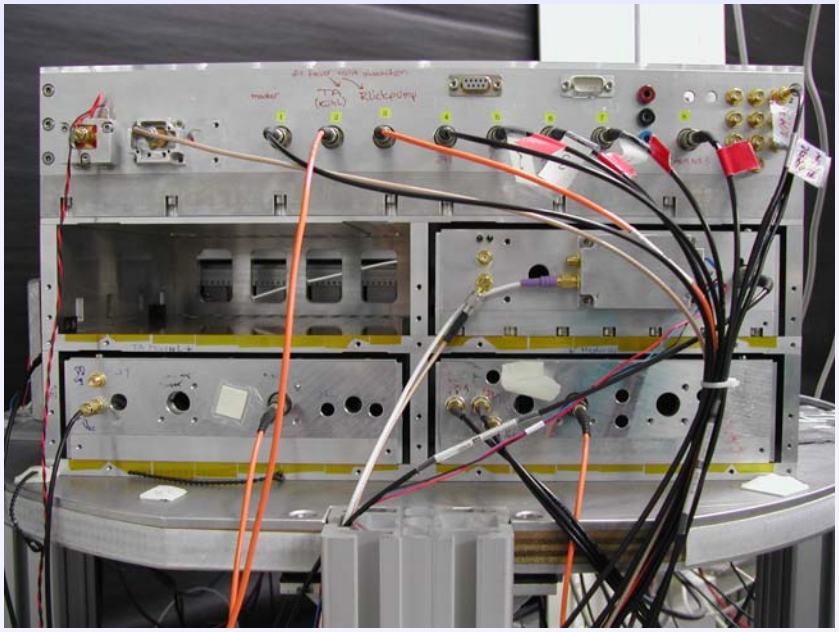
↓

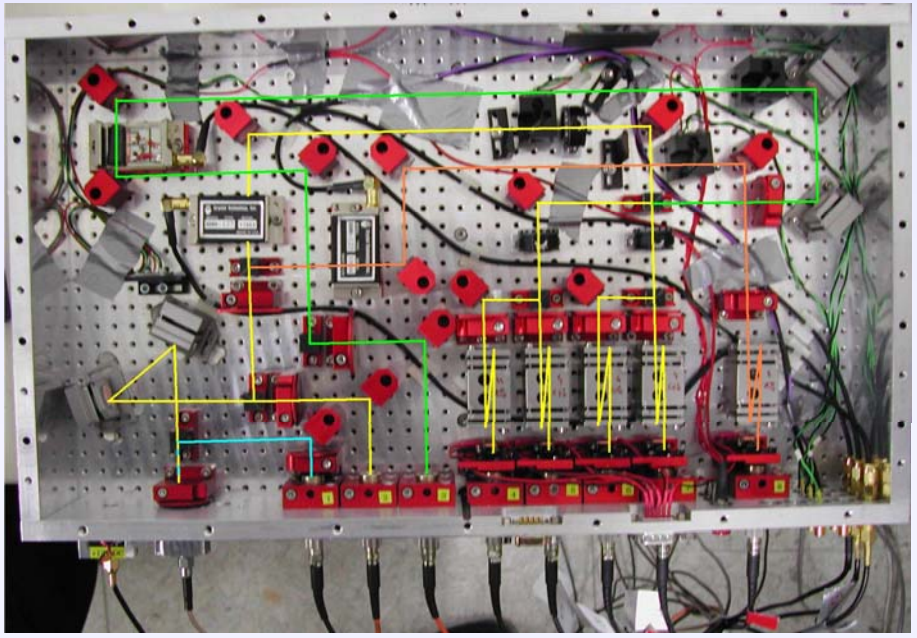




← MOPA module

Completed Laser System

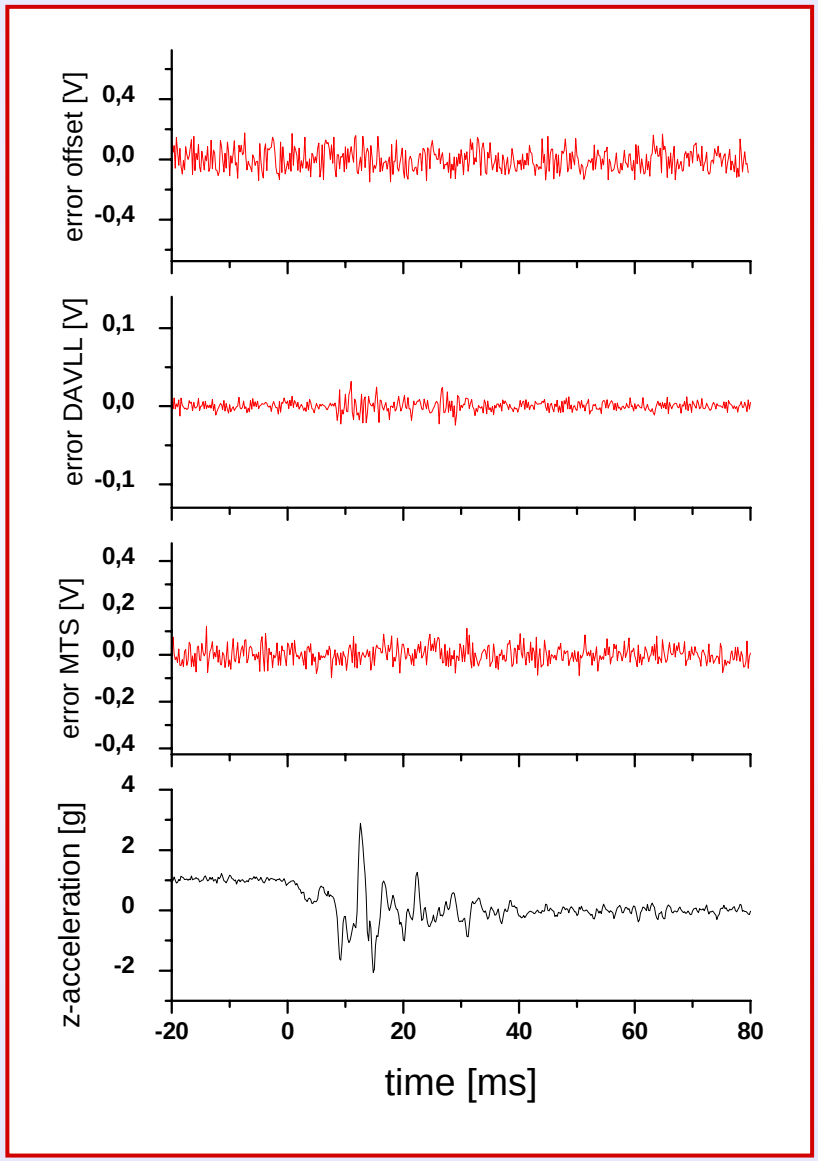




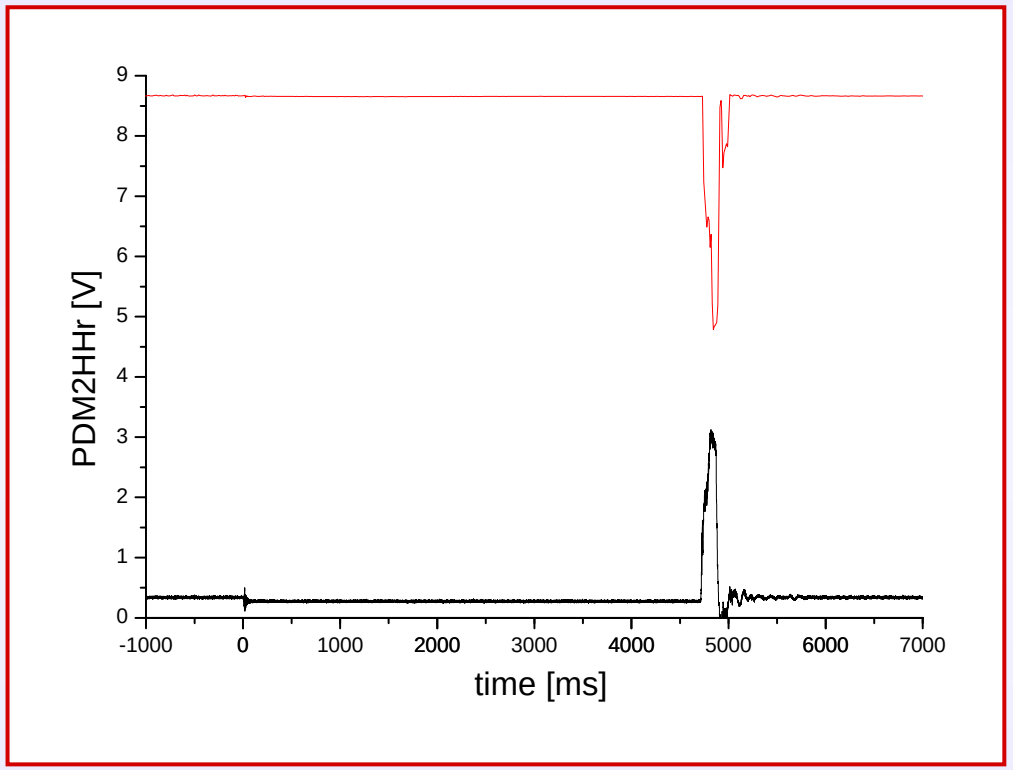
45 cm

- all components are integrated in the system
- laser modules guarantee a flexible setup
- robust laser design for drop tower experiments

Drop Tower Tests of Laser System

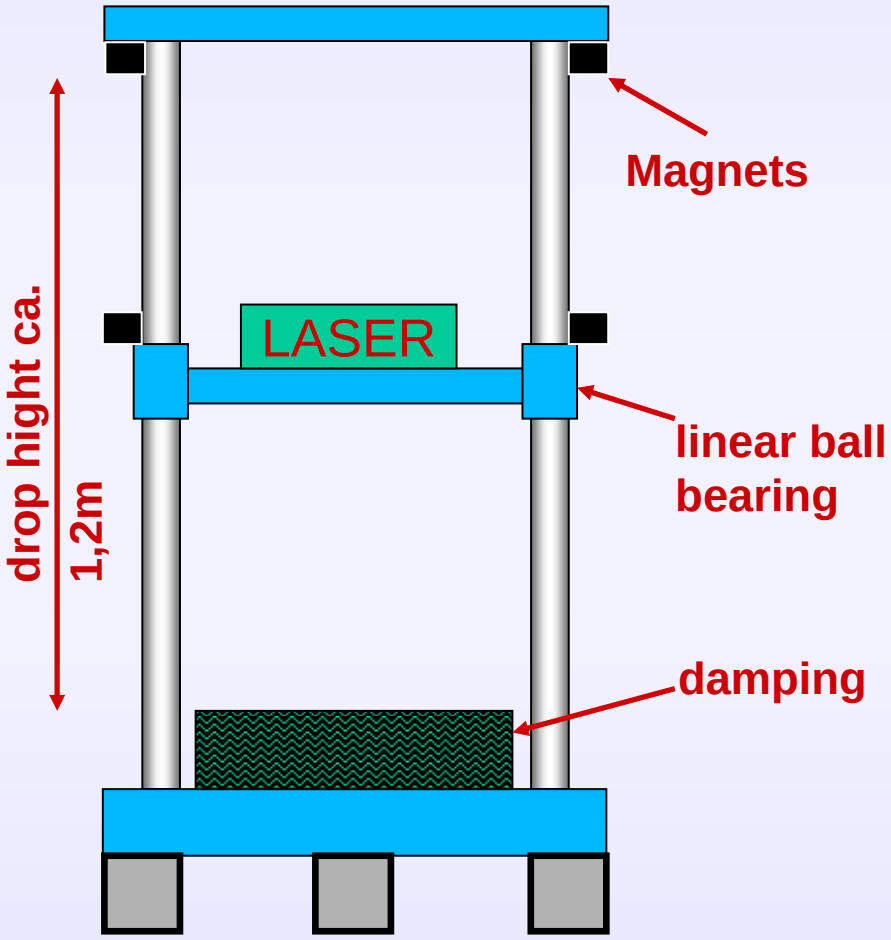


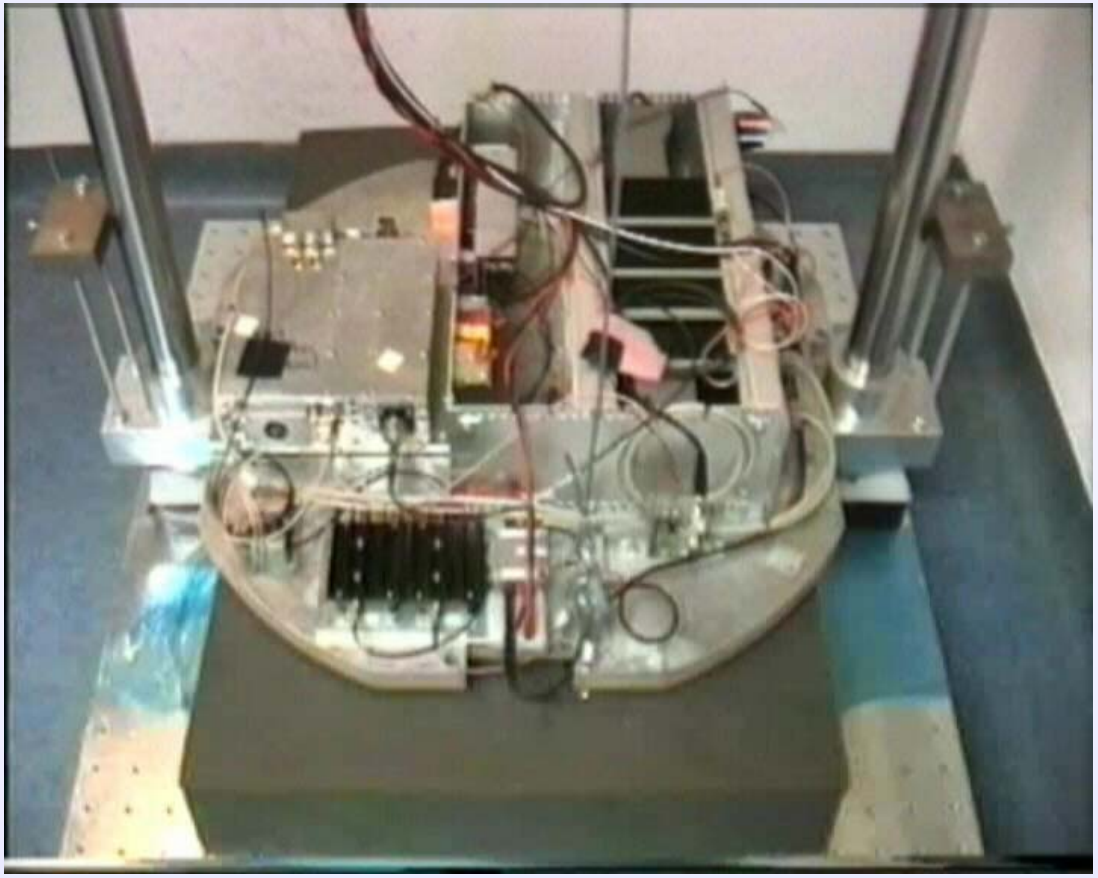
frequency stability test during release



fiber coupling stability during the flight

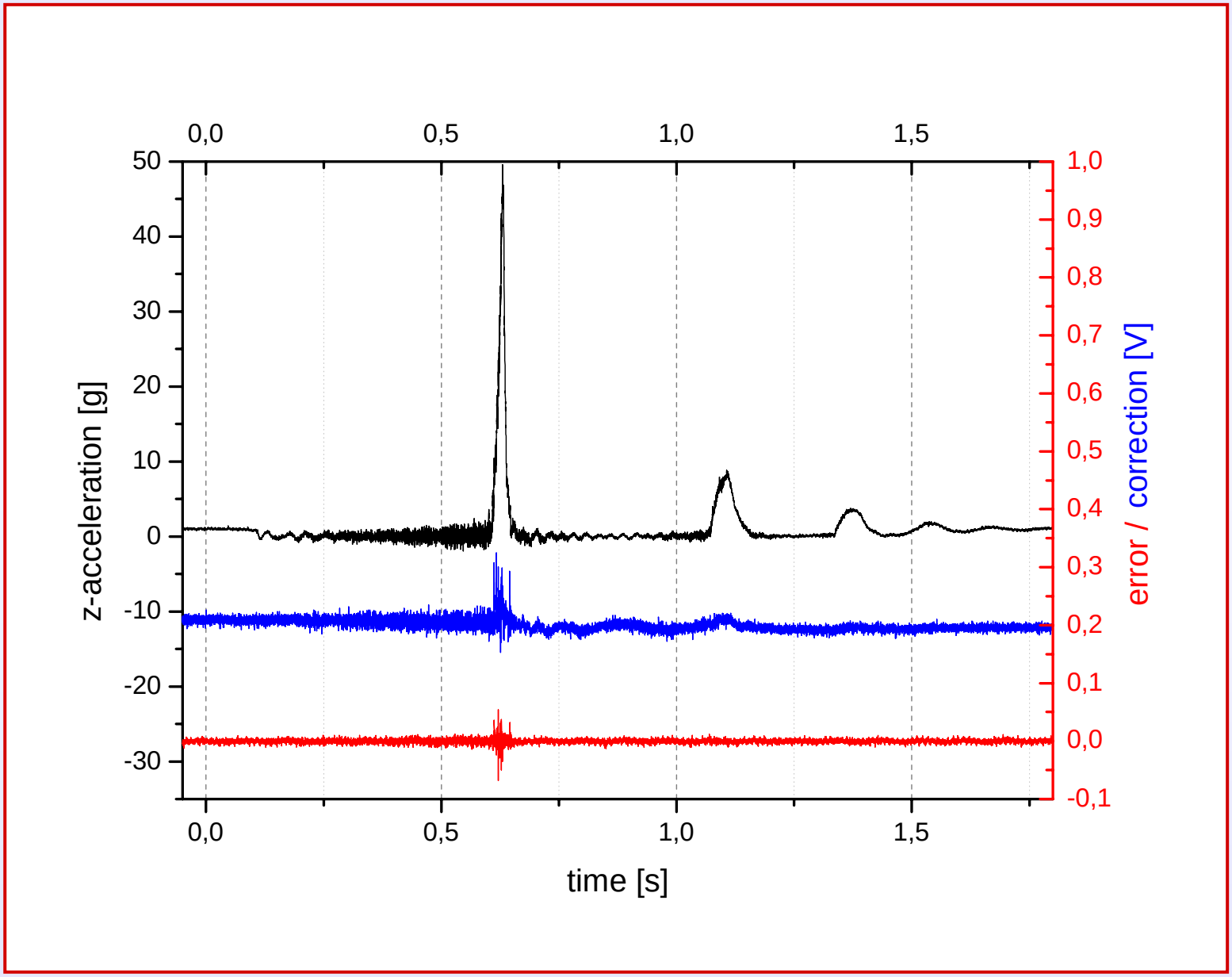
Laboratory Tests of Laser System



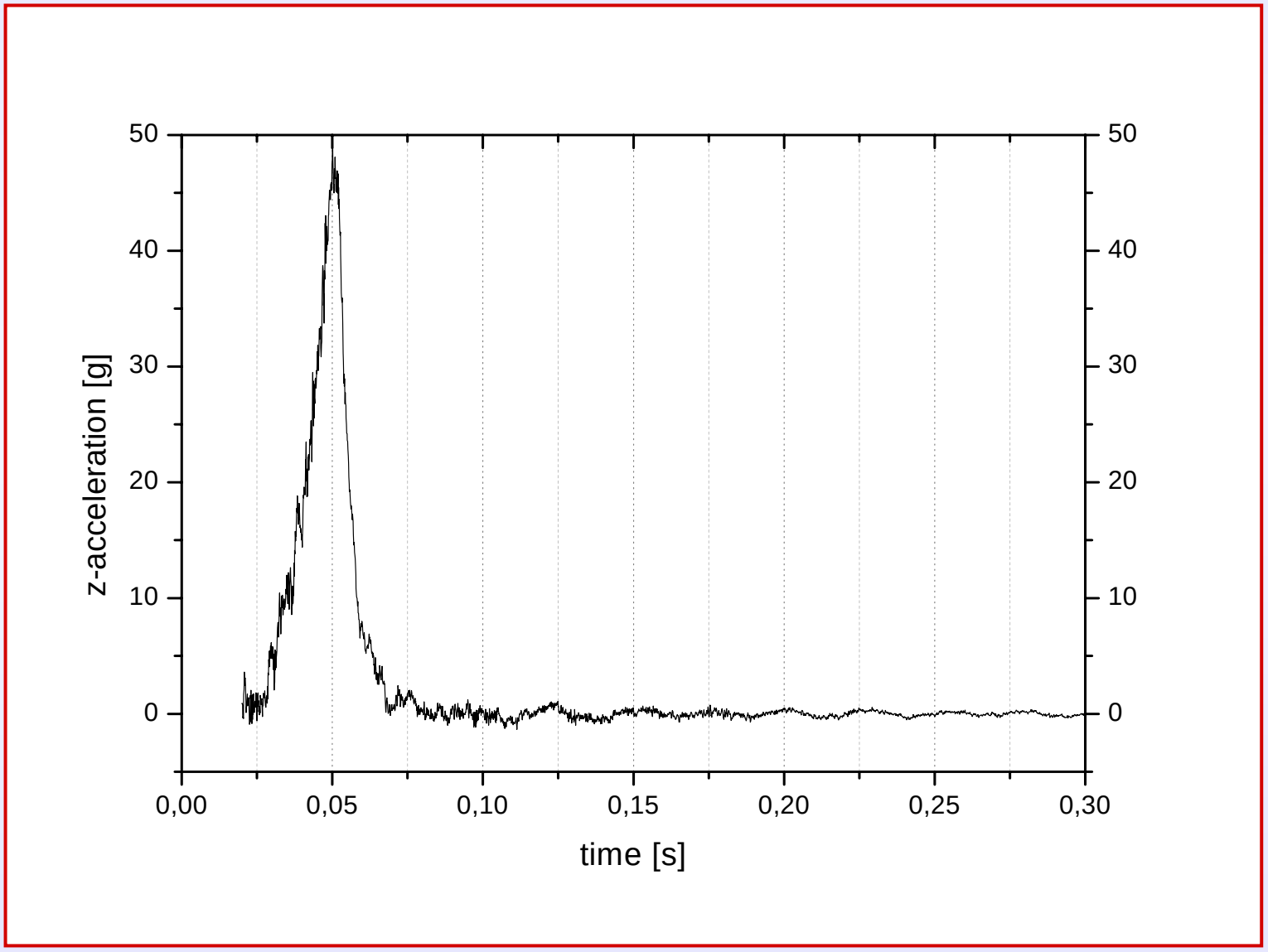


design: Katharina Elbs

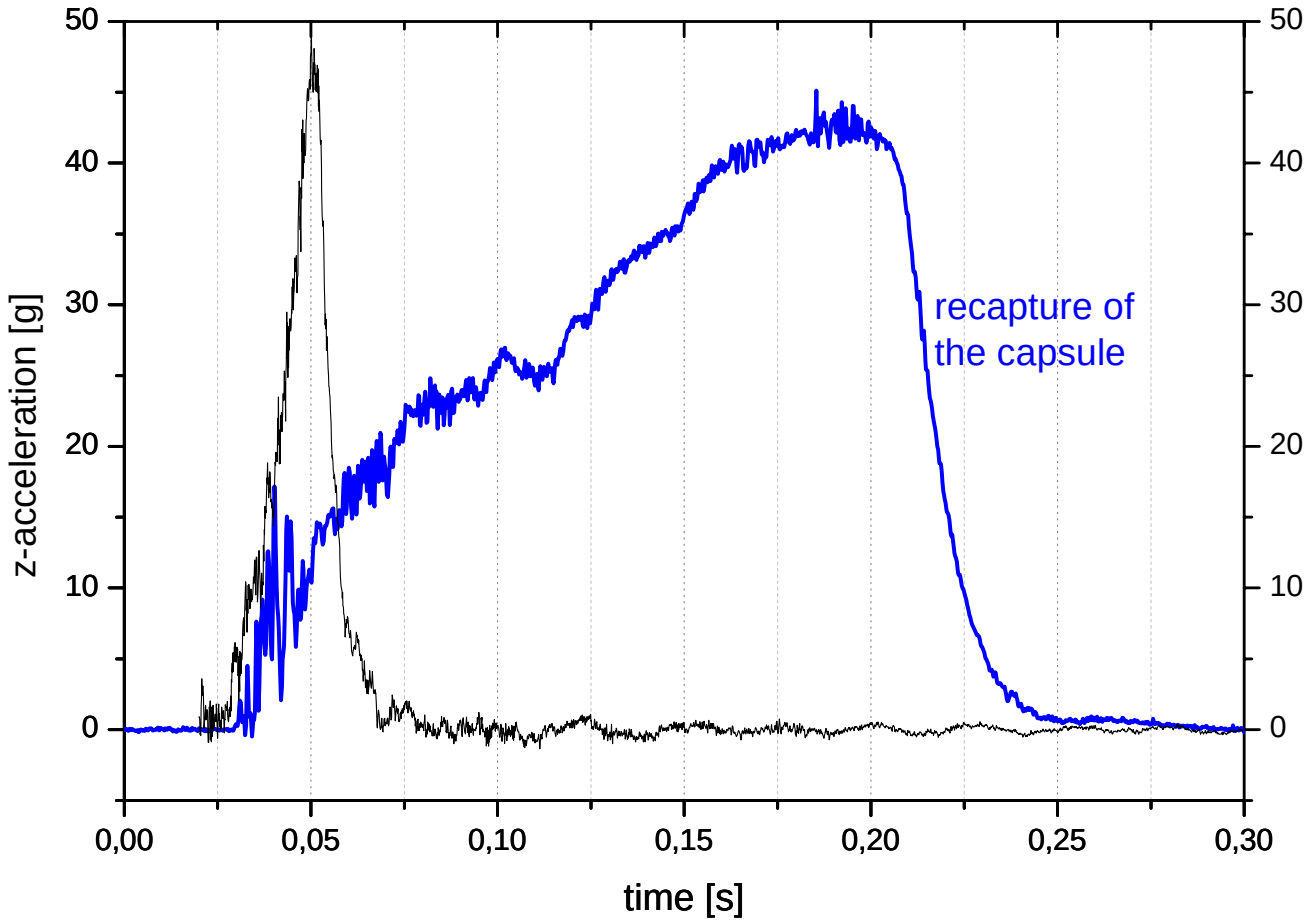
Laboratory Tests of Laser System



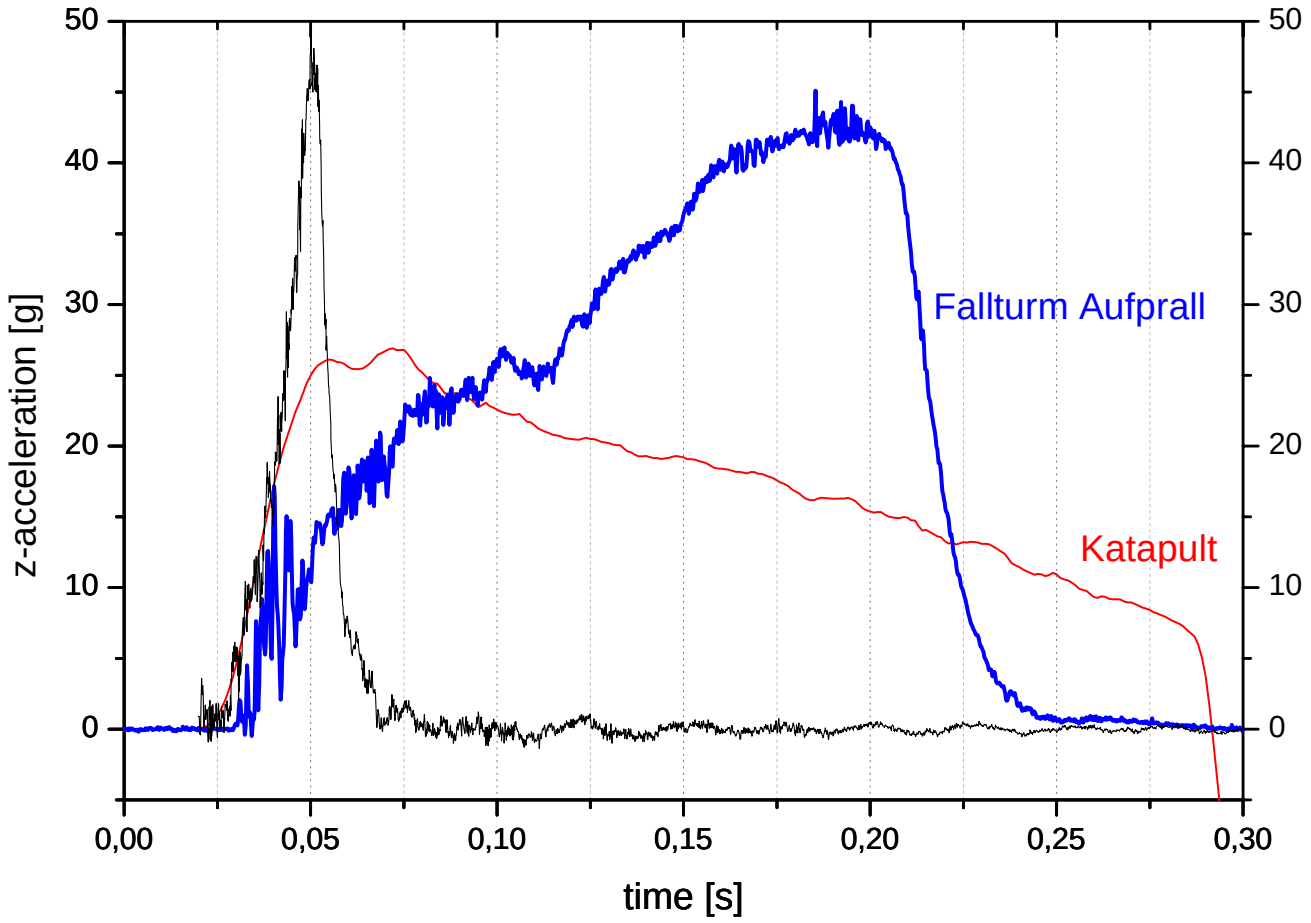
Laboratory Tests of Laser System



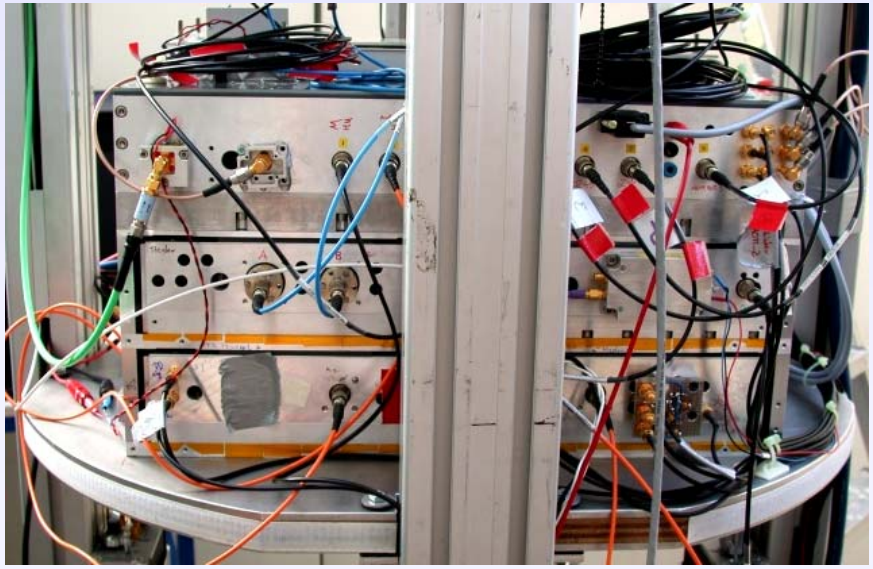
Laboratory Tests of Laser System

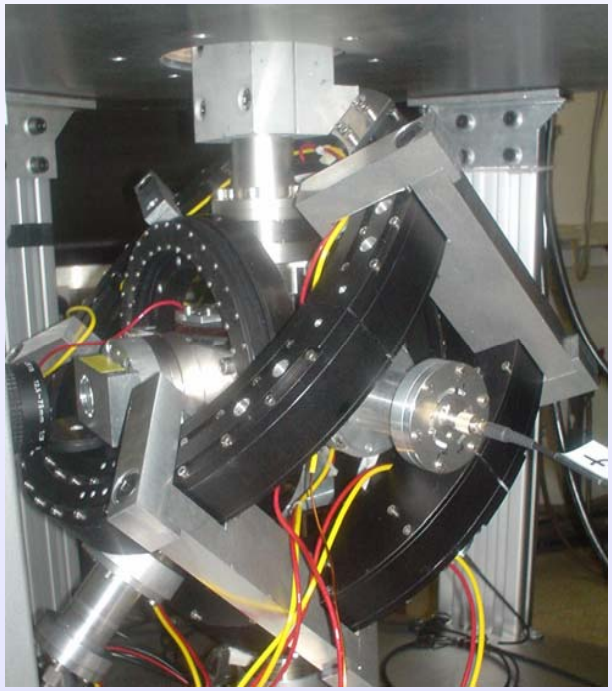


Laboratory Tests of Laser System

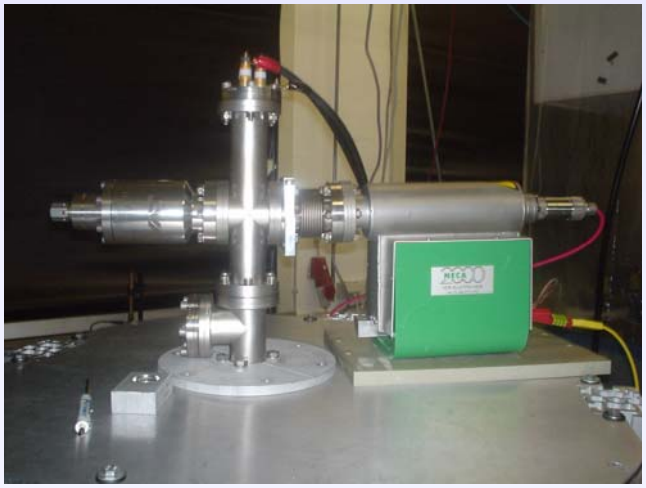


Drop Capsule Integration



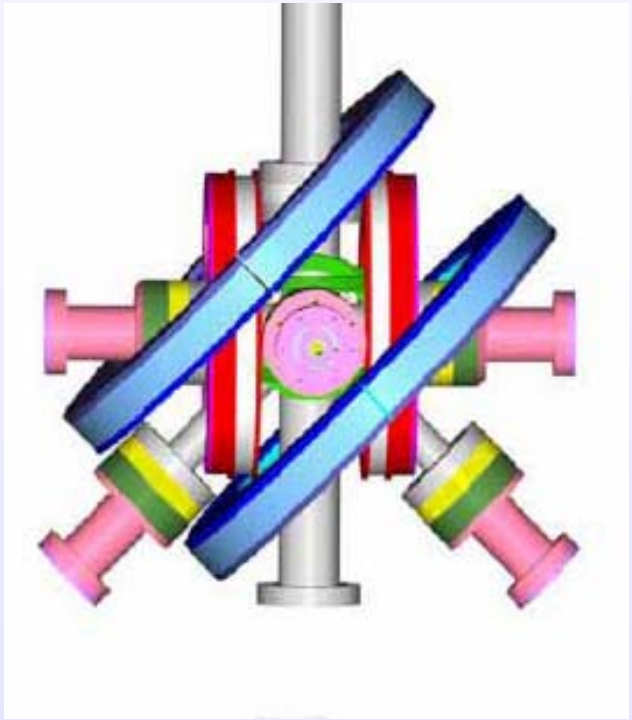


Experiment Chamber



Modified Iongetterpump (20l/s) to withstand strong forces (50g at impact)

Pressure in the lower 10^{-10} mbar regime

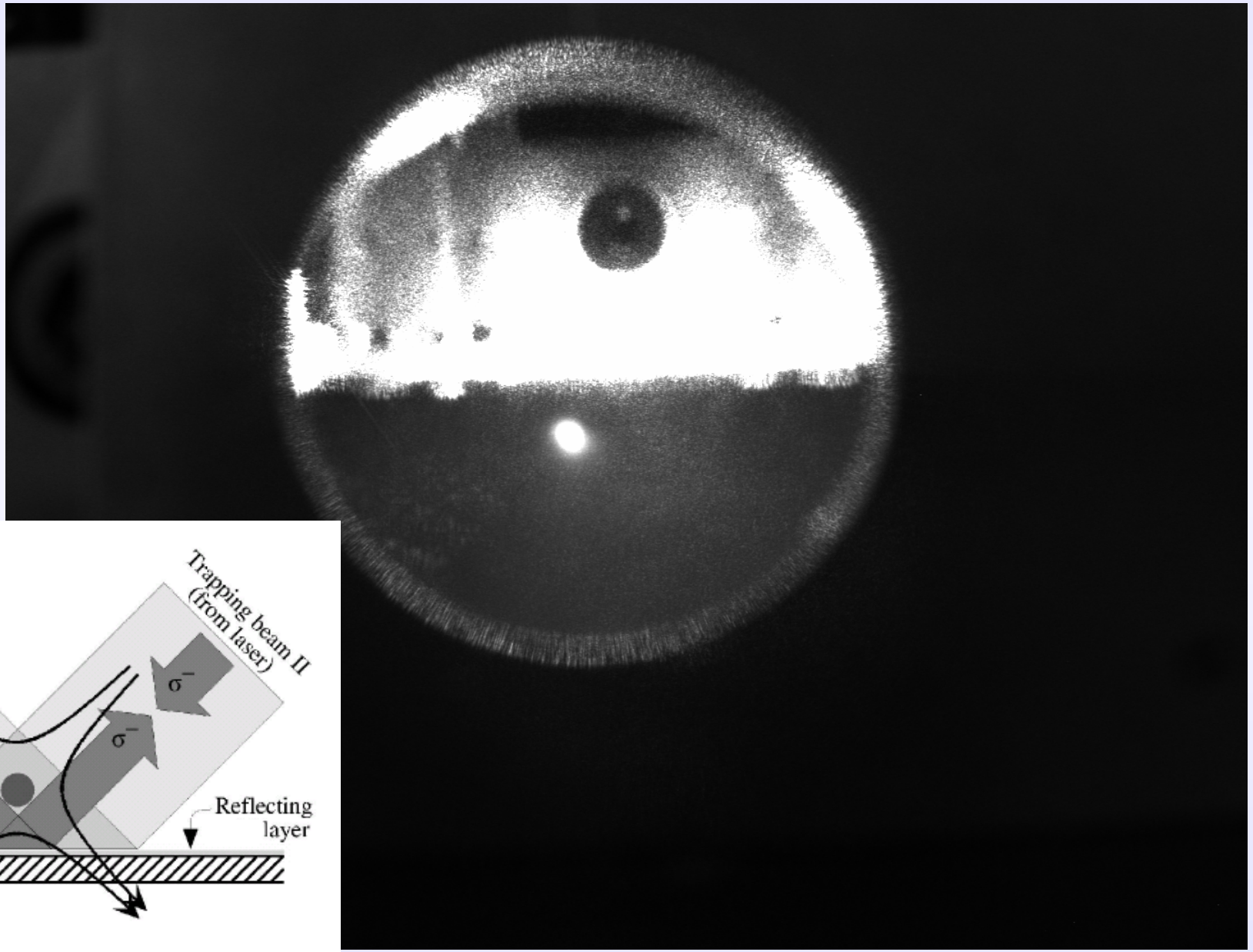


Single chamber design for size minimization

Fully fiber coupled

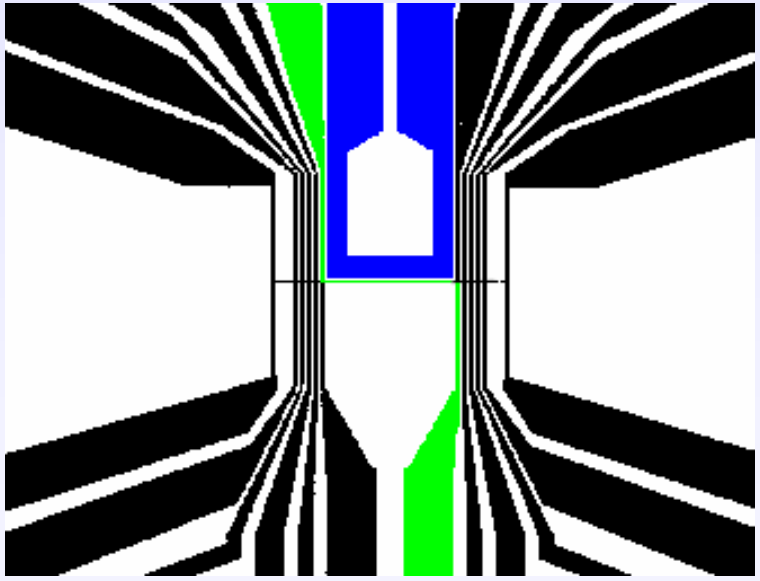
Robust coil arrangement

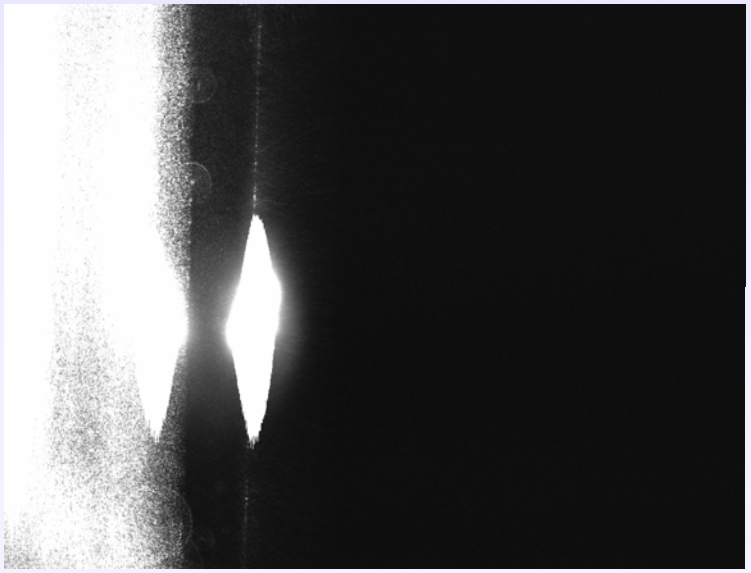
Mirror MOT

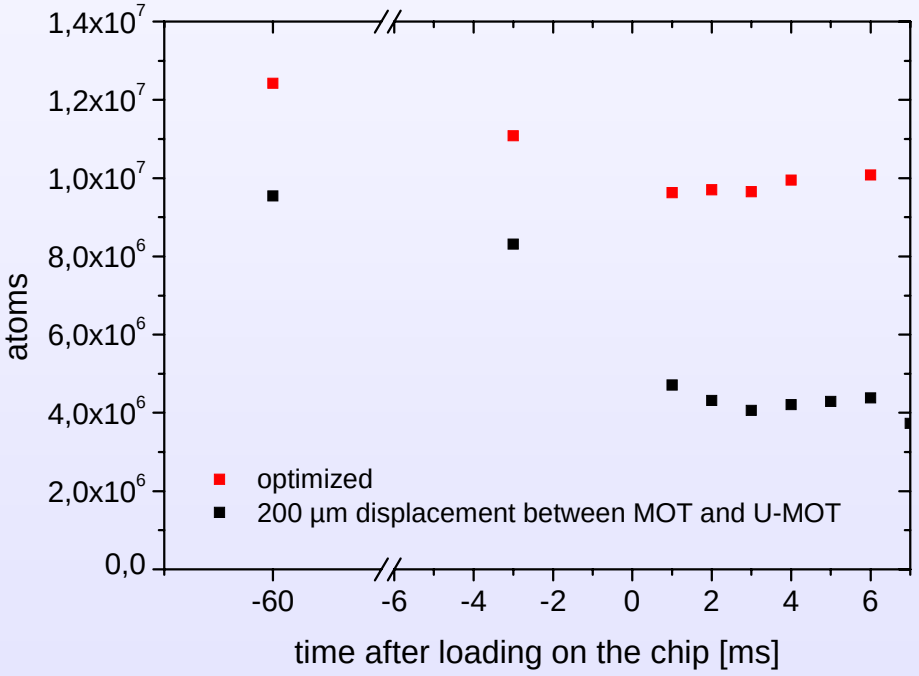


Trapping beam I
(from laser)
Trapping beam II
(from laser)
σ+
σ+
σ−
σ−
Reflecting
layer
Ga As-
substrate

Atom-Chip-MOT







- $12 \cdot 10^6$ atoms loaded into the external MOT,
- 85% transfer efficiency into chip-MOT,
- 40mK temperature after molasses-cooling,
- transfer to magnetic trap,
- evaporative cooling (in progress)

Outlook: Drop BEC Experiments

Next Steps:

- Evaporation and realization of lab BEC

- Transfer to the ZARM drop tower

- First BEC under microgravity

First experimental questions:

- Large scale time of flight expansion and interference

- Adiabatic trap expansion for lowest temperatures

- Equivalence of free fall and "free" space

The QUANTUS Team